# Quantification of Congestion – Calculating Benefits

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# ABSTRACT

Managing congestion is the key objective for many road improvements. However, standard planning strategies that are used to assess improvements for road sections with recurring congestion tend to consider only levels of service or broad estimates of benefits. To date, these strategies generally have not accounted for congestion or its costs in the benefit-cost analysis. The inclusion of monetary criteria, while not the sole basis for decision-making, allows stakeholders to understand the full benefits and costs of alternative actions.

To this end, unique methods to measure and quantify costs of congestion for Canadian cities were recently developed. Using existing volume and speed data, and drawing upon these quantification methods, changes in congestion that would be expected with various improvements can be assessed. These congestion changes are measured in terms of travel times [delay] and speeds, fuel consumption, air pollutants and greenhouse gas emissions. Costs to these impacts in terms of values of time for autos and trucks, fuel prices and costs of pollutants and greenhouse gases are established to quantitatively assess the impacts of proposed road improvements on congestion.

This method was recently applied in an operational study in York Region, just north of Toronto. The intersection of Highway 7 and Keele Street serves commuter traffic, but also is an important truck access to several industrial parks and a major intermodal terminal. The intersection routinely experiences congestion for substantial portions of the day. The study identified and evaluated over a dozen congestion mitigating strategies for the area. These strategies included changes to the roadway design, modifications to the signal operations and the application of new Intelligent Transportation Systems (ITS) technologies.

This paper presents the processes used to quantitatively assess these congestion mitigating strategies using a practical and realistic approach to measuring congestion. The merits of these processes are explained, including the improved ability to link planning, operational and design decisions. The findings and results for the various strategies are then documented in terms of the fiscal analysis and business cases.

# 1 Introduction

High traffic volumes combined with heavy commercial vehicle traffic is causing long delays and congestion in the area of Highway 7 at Keele Street in York Region, Ontario. The Regional Municipality of York, which has jurisdiction over the intersection, retained iTRANS Consulting Inc. to investigate ways to improve overall traffic operations in the vicinity of this intersection. The goal of this study was to reduce the congested conditions through the identification of both short term and long term solutions.

In order to obtain a more comprehensive understanding of the characteristics of the traffic including commuter demands and preferred routes for commuter and commercial vehicles in the vicinity of Highway 7 and Keele Street, a large study area was established (as shown in Figure 1). This large area captures traffic to and from Highways 400 and 407 and assesses the transportation system in the area. The study area limits were determined to be Steeles Avenue to the south, Rutherford Road to the north, Highway 400 to the west and Dufferin Street to the east. Highway 407, running parallel to Highway 7 within the study area is a toll highway. Consideration of this large study area incorporates the influences of the surrounding freeway network and the flow patterns for the greater overall area.

The longest delays in the study area that are due to congestion are experienced on Highway 7 between the limits of Highway 400 and Dufferin Street. Congestion mitigation strategies were therefore expected to offer the greatest benefits to traffic along this stretch of road. As a result, the comprehensive analysis of benefits and costs due to congestion was focussed specifically on Highway 7 between Highway 400 and Dufferin Street.

The study was undertaken in three main phases; a review of existing conditions, the identification and evaluation of alternative congestion mitigating strategies and the development of a realistic and responsible staging plan.

The identification and analysis of a wide range of alternative strategies designed to mitigate congestion was accomplished by assembling a group of senior experts in design, traffic operations, safety and transportation planning. Brainstorming sessions were held with the entire group to identify as many strategies as possible. Those strategies which were deemed to be at least feasible were short-listed for a more thorough analysis to obtain a list of strategies with promise.

Each short-listed strategy was then assessed for its potential to mitigate congestion. This process required the acquisition of travel time information for the existing Highway 7 corridor. Travel times were acquired for uncongested conditions as well as for each of three peak periods (morning, mid-day and evening). A unique process to analyze the differences in travel times and to identify levels of congestion from these differences allowed for the determination of an overall cost of congestion. Computer models were then used to assess the impacts of the various short-listed alternatives on the travel times and thus on the costs of congestion.

A staging plan was then developed as a guide toward implementing the strategies with promise (i.e. complementary strategies with positive benefit-cost ratios). The staging plan also considers opportunities (such as operations programs and planned construction contracts) as well as the potential payback in benefits. Conceptual designs were then prepared for each recommended strategy.

## 2 Identified Congestion Mitigation Strategies

A team of senior people experienced in a wide range of engineering disciplines gathered with representatives from ratepayers associations to brainstorm solutions to existing traffic challenges throughout the Highway 7 and Keele Street study area. The goal of the exercise was to establish a comprehensive list of any and all strategies that may potentially alleviate congestion along both corridors. From this session a number of strategies were identified.

**Table 1 - Identified Strategies** summarizes all of the strategies identified during the brainstorming exercise. Each strategy is accompanied by a general definition as well as a description of how it may apply to the study area. The table also provides some of the preliminary assessment criteria that were used to establish if the strategy merited further evaluation.

Definitions for travel demand management strategies were adopted from the Victoria Transport Policy Institute (www.vtpi.org). Definitions for design strategies were established during the multidisciplinary brainstorming sessions and the ITS strategies were defined with reference to the ITS Canada (www.itscanada.ca) and ITS America (www.itsa.org) websites.

The generic definitions were used as a basis to help establish the scope and application of the strategy to the characteristics of the Highway 7 and Keele Street corridors. For example, some strategies are applicable to the Highway 7 and Keele Street intersection only while others consider a much broader area.

Strategies were short-listed for further consideration according to the following assessment criteria:

- Is the strategy consistent with York Region's authority and practices;
- Is the strategy sensitive to the requirements of local stakeholders (residents and businesses);
- Does the strategy show promise in consideration of generic costs and benefits; and
- Is the strategy practical and realistic to implement.

Discussions with the Region's project team were held to obtain consensus on those strategies that were short-listed for further evaluation.

### 2.1 Secondary Assessments

Access management and roundabouts were identified as strategies for further consideration. However, as the access management practice is currently in place through the development approvals procedures, it was not carried forward as a strategy for further evaluation. Similarly, due to planned transit improvements along the Highway 7 corridor and property constraints, a roundabout at the Highway 7 and Keele Street intersection was also not considered to be a viable strategy at this time and was not carried forward for further evaluation.

## 3 Comparison of Assessment Methodologies

Congestion has historically been difficult to quantify for the assessment of improvements to roadways. The more traditional planning approach is to identify some acceptable level of service and a forecasted future traffic volume. The result is a general idea of the capacity required which in turn suggests candidate solutions.

While this approach is adequate to establish major road changes such as widening projects, it does not lend itself well for the evaluation of less drastic strategies designed to mitigate congestion in other ways. For example, it is difficult to assess the potential benefits of a by-pass road around a congested intersection, or a grade separation for left turn movement. The true benefits of these alternatives must reflect the improvements to the operations of traffic.

Recent iTRANS-directed research on congestion for Transport Canada provides some guidance on methods for establishing the costs of congestion.[1] . The research focused on recurrent congestion; that is, congestion that occurs from the day-to-day build-up of traffic.

The study noted the importance of estimating values of time (VoT) for different types of vehicles. To this end, for the purposes of this analysis VoT were derived for heavy trucks, light trucks and non-commercial autos. As the existing traffic counts used for the evaluation of various strategies combine light trucks and heavy trucks, an average VoT of $32.69 /hour was derived (based on $31.39 /hour for light trucks and $33.99/ hour for heavy trucks). These figures reflect May 2005 wages for truck drivers in Ontario (from Stats Can) and consider both driver's time (wage) and the value of the cargo. The average VoT for autos is $22.71/hour and there is a difference between work trips ($30.86/hour) and other trips ($9.50/hour). According to Transportation Tomorrow Survey, work trips represent 55% of all auto person trips over a 24 hour period.

[1] Transport Canada, *The Cost of Urban Congestion in Canada*, Summary Report, March 22, 2006 (see http://www.tc.gc.ca/mediaroom/releases/nat/2006/06-h006e.htm), .

It is important to note that there are different ways to calculate VoT.  For example, for truck VoT, it makes a difference as to whether the trip is short-haul internal to the Greater Toronto Area (GTA) or long-haul (going out of town), because the driver is paid differently according to one or the other.  Also, the treatment of the cargo varies in the literature:  in some cases, it may be worth much more than the driver's wage (so as to obviate the wage).

The VoT values are generally applied against the time lost due to congestion. The time lost due to congestion should be considered only for the duration during which the vehicle was traveling slower than the free flow speed. The time lost due to congestion then is the difference between the actual time spent traveling in congestion and the time they would have spent traveling the same length at the free flow speed. Determining the free flow speed for arterials presents some unique challenges. The challenges are discussed further below.

### 3.1 Measuring and Estimating Travel Times

iTREC® was used to measure the travel times along the Highway 7 corridor and Synchro was used to assess the impacts of candidate improvements.

iTREC is a Global Positioning System (GPS) based travel time program that records and analyzes a travel profile. A laptop computer was used with a GPS to record vehicle position, time and speed along the entire route at a one second resolution. iTREC was then used to compare: travel times, average speeds, number of stops and stopped delay for the scenarios discussed below.

The analysis of congestion on arterials presents many challenges. It is easier to recognize congestion from the speed profile of a freeway; any travel less than a threshold speed can be defined as congestion. However, on arterials there are many road elements that will require traffic to slow or stop. The most common and most important source of delay is traffic signals (i.e., vehicles must stop when the signal is red, regardless of the volume of traffic on the road). As such, normal traffic operations on arterials result in at least some stops and delays to traffic at any level of service. This situation was also experienced on Highway 7 as shown in Figure 2.

To negate the effects of these “normal” arterial delays in determining congestion, the travel times reflecting “free flow” conditions were measured. Free flow conditions were assumed to exist during the pre-morning peak hours. Several runs were conducted in each direction during these hours to obtain a more representative sample of the actual traffic operations. The average travel time was then determined using iTREC.

iTREC was also used to collect travel time information for each of the morning, mid-day and afternoon peak periods. Several runs were again averaged together to represent the operations for the respective peak period.

The cost of congestion analysis was carried out for a number of independent road segments where a segment was defined as the section of road between two signalized intersections. This definition allows for direct comparisons with the Synchro outputs and allows for variations in vehicle volumes and traffic composition to be reflected in the calculations.

The difference in travel times between the free flow condition and each of the peak conditions for each segment was assumed to be the result of congestion. Stops and delays from other sources (such as more frequent stopped transit vehicles or more frequent turning traffic than in the free flow conditions) were assumed to have a minimal influence. The difference in travel times was then multiplied by the traffic volumes (according to vehicle type) and the appropriate value of time to derive the cost of congestion. The process was repeated for each segment and for each peak period. The costs were summed to arrive at a total cost of congestion by direction.

Synchro was then calibrated for each peak period to reflect the existing travel times measured on-street. Synchro was also used to simulate the traffic operations expected with the inclusion of each of the short-listed congestion mitigation treatments. The difference in travel times established by Synchro between existing and “treated” was then subtracted from the travel times measured by iTREC for the corresponding peak periods. Revised costs of congestion were then re-calculated to obtain a measure of the benefits (in terms of reduced congestion) for each candidate treatment.

# 4 Cost of Congestion Estimates

The benefits for each strategy are largely a result of the reduction in operating costs due to lower congestion through the study corridor. The benefits associated with reduced maintenance were considered negligible for all of the strategies evaluated.

The benefits for each strategy can be derived from the difference in the cost of congestion with and without the identified strategy. Given the unique nature of the Highway 7 corridor (e.g. parallel to Highway 407, a toll highway), it was difficult to quantify the expected changes in traffic volumes that may result from the implementation of motorist advisory systems. As a result, this strategy was tested for various levels of diversion, specifically 2%, 5% and 10% of through traffic volumes.

The total daily costs of congestion, as estimated through the computer models, are shown in Table 2. Table 2 also lists the assumed duration for each peak period. Although congestion may routinely occur outside of these hours (and also on weekends) only two hours in the AM Peak, and three hours for each of the mid-day and PM Peak periods were considered for the overall evaluation of benefits (making these estimates fairly conservative).

## 4.1 Results

Table 3 provides the cost-benefit ratios for each strategy. As shown in Table 3, the benefit to cost ratio for the Langstaff Connection strategy and the CN/Hwy 7 Access strategy were estimated to be below 1. As a result, these strategies were not considered further in the development of a staging plan for the Region.

By necessity, the strategies involving grade separation were assessed against each other. For example, the implementation of left turn flyovers eliminates the ability to grade separate the intersection or establish a point diamond interchange. In these cases, the strategy with the best benefit to cost ratio was selected for consideration in the staging plan (which was determined to be grade separation with the connector road).

# 5 Future Research

For this study, the free flow condition was measured as the operations of traffic during pre-morning peak conditions. Future research should assess the perception of the free flow condition for an arterial in terms of acceptability to the road authority or the public. For example, some congestion may be viewed as tolerable either for certain vehicle types or for the public as a whole. If so, the free flow condition should be either measured near the threshold of the acceptable conditions, or measured in free flow conditions and adjusted accordingly.

The *Cost of Urban Congestion in Canada*[1] research assumed a threshold speed for freeway traffic. Congestion was defined as the portion of travel that takes place below this threshold speed. It was also recognized that this threshold may vary for different urban centres across Canada. It is likely that a similar threshold, if defined for arterials would also differ amongst road authorities.

# 6 Conclusion

The Region of York has undertaken a Traffic Operational Review in an attempt to improve traffic conditions in the vicinity of Highway 7 and Keele Street. The unique characteristics of the study area combined with the high traffic demands require creative and proactive solutions in order to address recurring traffic congestion.

Strategies that address the needs of the traffic and road users were developed by a multi-disciplinary team of experts through brainstorming sessions. They involve strategies consistent with the design and construction of new road elements, the introduction of ITS systems and on-going network optimization. Those strategies that were deemed to be consistent with the Region’s authority and practices were carried forward for further consideration.

This project adopted a ground-breaking approach to estimating congestion-reduction benefits for potential strategies . Travel time profiles and computer models were used to establish the relative benefits including the costs associated with recurring congestion.

These benefits were then compared against costs for each strategy to obtain relative benefit to cost ratios for each candidate congestion mitigation strategy.

## 7 References

1. Transport Canada, *The Cost of Urban Congestion in Canada*, Summary Report, March 22, 2006 (see http://www.tc.gc.ca/mediaroom/releases/nat/2006/06-h006e.htm).

**Table 1 – Identified Strategies**

| Strategy | Description | Short Listing Criteria |
|---|---|---|
| **Travel Demand Management Strategies** | | |
| **Road Pricing / Congestion Pricing** | Road Pricing involves charging motorists directly for driving on a particular road or in a particular area. Congestion Pricing is Road Pricing with higher rates during congested periods. Implementation of this strategy would encourage traffic to find alternatives routes other than those in the study area. | This option is not consistent with the Region's policy of providing service to all areas and constituents throughout the Region.<br><br>This strategy was not short-listed. |
| **Commute Trip Reduction** | Commute Trip Reduction programs encourage commuters to use alternative modes for trips to work and school. Such programs tend to be particularly effective if they incorporate suitable Financial Incentives, such as Transit Benefits or Parking Pricing. Implementation of this strategy would require working with local businesses to encourage trip reductions during the highest commuter hours. | According to the EMME/2 computer model, the corridor services commuters traveling over a wide area of influence. Effective commute trip reduction strategies are likely to be costly and difficult to implement.<br><br>This strategy was not short-listed. |
| **Flextime** | Flextime allows employees some flexibility in their daily work schedules. This shifts travel from peak to off-peak periods, which can reduce traffic congestion directly. Implementation of this strategy would require working with local businesses to encourage flexible hours of operation. | According to the EMME/2 computer model, the Highway 7 corridor services commuters traveling over a wide area of influence. Effective flextime programs would likely be required on a very broad basis and would therefore be costly and difficult to implement effectively.<br><br>This option was not short-listed. |
| **Parking Management and Parking Pricing** | Parking Management and Parking Pricing strategies can be an effective way to reduce automobile travel, and tend to be particularly effective in urban areas where congestion problems are greatest. Since most urban-peak highway trips are for commuting, employee parking pricing can have a similar effect as a road toll. Parking Management would be applied to the study area by introducing parking meters and public parking areas. | Most parking facilities within the study area are on private property. Parking pricing would therefore not apply.<br><br>This strategy was not short-listed. |

| | | |
|---|---|---|
| **Distance-Based Pricing** | Converting vehicle insurance and registration fees into distance-based charges can provide a significant financial incentive to reduce driving. Distance-based fees affects all travel, not just travel on certain highways, and so provides congestion reduction benefits on surface streets without shifting traffic to other routes. | This strategy is not under the authority of York Region to implement.<br><br>This strategy was not short-listed. |
| **Telecommuting** | Telecommuting involves the use of telecommunications to substitute for physical travel. It includes telecommuting, employees with mobile work and people who are self-employed and able to work from a home office due to efficient communications. This gives people a way to avoid traveling under congested conditions. Implementation of this strategy would require working with local businesses to encourage availability of telecommuting equipment. | According to the EMME/2 computer model, the Highway 7 corridor services commuters traveling over a wide area of influence. Effective telecommuting programs would likely be required on a very broad basis and would therefore be costly and difficult to implement effectively.<br><br>This strategy was not short-listed. |
| **Freight Transport Management** | Freight trucks can make a relatively large contribution to congestion, due to their large size and slow acceleration. A large truck can contribute as much congestion as 3-6 passenger cars. Implementation of Freight Transport Management to the study area includes various strategies of increasing the efficiency of freight and commercial transport while reducing total freight traffic and shifting freight to less congested routes. | The Highway 7 and Keele Street corridors provide an essential service to local business involved in freight movement, particularly with the presence of the CN transfer facility. No viable, less congested routes are readily available. The requirements of the local businesses and the mandate of the Region to service businesses and the public preclude this strategy.<br><br>This strategy was not short-listed. |
| **Access Management** | Access Management is a term used by transportation professionals for coordination between roadway design and land use to improve transportation. It involves changing land use planning and roadway design practices to limit the number of driveways and intersections on arterials and highways, constructing medians to control turning movements, encouraging clustered development, and creating more pedestrian-oriented street designs. This reduces “friction” along the roadway, which tends to increase traffic speeds, reduce congestion delays and reduce crashes. | Much of the study area includes controlled or limited access. New restrictions will require re-development of properties and a site-plan approval process. The Region should continue to strive to balance access with reasonable control points.<br><br>Although adopted, no further evaluation is necessary for this strategy. |

| Design Strategies | | |
| --- | --- | --- |
| **Roundabouts** | A roundabout is an intersection built with a circular island around which traffic rotates in one direction. Roundabouts are an alternative to stop signs and traffic signals at small and medium-size intersections that can reduce stopping requirements and avoid traffic "platoons" (vehicles bunching up at intersections. This option involves the replacement of the existing Highway 7 at Keele intersection with a roundabout. | A roundabout has been identified by local residents and the City of Vaughan as an option to be considered.<br><br>This strategy was short-listed for further consideration. |
| **Connector (Service) Road** | A connector road links two other roads to provide either a more direct path or a bypass. Implementation of a connector road in the study area would likely involve traffic signals at a point west of Keele off of Highway 7. The current development and land parcels in the area would support connecting this road to the existing Administration Road which already has signals on Keele Street. | A connector road was assessed as a viable future alternative.<br><br>This strategy was short-listed for further consideration. |
| **Grade Separation with Connector Road** | This option consists of the connector road listed previously, with a complete grade separation between Highway 7 and Keele Street. | A fully grade separated intersection with a connector road is already a proven strategy along the Highway 7 corridor (at Bayview, Yonge, Bathurst and Dufferin).<br><br>This strategy was short-listed for further consideration. |
| **Left Turn Flyovers** | Left turn flyovers are used to grade separate the left turn movements through an intersection. The removal of the left turn vehicles from the at-grade intersection allows for more signal time to be used for other movements and reduces the number of vehicle conflicts. | Left turn flyovers for the Highway 7 left turn movements at the Keele Street intersection may have significant benefits on the overall delay, safety and operations of the Highway 7 at Keele Street intersection.<br><br>This strategy was short-listed for further consideration. |
| **Grade Separated, Diamond Point Intersection** | This strategy considers grade separating the through movements on Highway 7. Traffic from Highway 7 destined to turn onto Keele Street would access the at-grade portion of the intersection using ramps. All of the traffic on Keele Street would also access the at-grade portion of the intersection. | Removing the Highway 7 through traffic from the intersection may have significant benefits on the overall delay, safety and operations of the Highway 7 and Keele Street intersection This strategy was short-listed for further consideration. |

| | | |
|---|---|---|
| **Connection of Langstaff Road** | Langstaff Road is currently discontinuous over the CN rail lands. Connecting Langstaff Road across this property would require elevating the road above the railway tracks. | The approximate length of the grade separation is 2 km. The connection of Langstaff Road would complete the grid concession pattern for the arterial road network.<br><br>This strategy was short-listed for further consideration. |
| **Intelligent Transportation Systems** | | |
| **Traffic Adaptive Control and Network Optimization** | Adaptive traffic signal control allows for second-by-second adjustments to the traffic control signal timing to accommodate fluctuations in traffic demands. SCOOT and SCATS are existing traffic adaptive kernels that are in use throughout North America. | The traffic signals along Highway 7 and along Keele Street (within the study area) would be connected to a separate traffic adaptive control system. Additional detectors would be installed to monitor traffic fluctuations. Traffic adaptive control may help to alleviate congestion by responding more dynamically to the traffic demands.<br><br>This strategy was short-listed for further consideration. |
| **Motorist Information Systems** | Motorist Information Systems can include changeable message signs, radio reports and Internet information about traffic conditions. These can let motorists anticipate conditions. | Changeable message signs would likely be located along the Highway 7 corridor at Pine Valley to the west and Dufferin Street to the east to address the heaviest congestion. The signs could provide drivers with an approximate travel time to a downstream point. This information may assist some drivers to select an alternative route if the traffic congestion is heavy along Highway 7.<br><br>This strategy was short-listed for further consideration. |
| **Real-Time Traffic Web-Site** | A closed circuit television camera located at the intersection of Highway 7 and Keele Street broadcasting live information through a web-site for commuters and local businesses to access prior to selecting their route of choice. | Commuters and local businesses may adjust their travel either temporally (travel at a different time) or spatially (select a different route).<br><br>This strategy was short-listed for further consideration. |

**Table 2**:

**Table 2 – Total Costs of Congestion for Each Strategy**

| | | AM Peak | PM Peak | Mid-Day Peak | *Daily Total* |
|---|---|---|---|---|---|
| Duration of Peak Period (hrs) | | 2 | 3 | 3 | |
| Strategy | | | | | |
| Existing | Option 0 | $ 4,907.29 | $ 8,850.34 | $ 7,646.91 | *$ 59,306.33* |
| Keele St. Widening | Option 1 | $ 4,554.41 | $ 7,416.13 | $ 7,646.95 | *$ 54,298.07* |
| CN/Hwy 7 Access | Option 2 | $ 4,574.57 | $ 8,004.28 | $ 8,659.61 | *$ 59,140.82* |
| Grade Separation | Option 3 | $ 3,966.89 | $ 8,091.97 | $ 6,584.99 | *$ 51,964.70* |
| WB/EB LT Flyovers | Option 4 | $ 4,263.53 | $ 7,656.74 | $ 7,265.67 | *$ 53,294.29* |
| Point Diamond Interchange | Option 5 | $ 3,684.17 | $ 7,114.07 | $ 7,487.95 | *$ 51,174.43* |
| Network Optimization | Option 6 | $ 3,849.43 | $ 8,385.08 | $ 7,244.82 | *$ 54,588.57* |
| ITS | Option 7 (2%) | $ 4,589.01 | $ 8,418.54 | $ 7,584.04 | *$ 57,185.75* |
| ITS | Option 7 (5%) | $ 4,182.79 | $ 7,812.99 | $ 7,294.50 | *$ 53,688.06* |
| ITS | Option 7 (10%) | $ 3,803.64 | $ 7,023.83 | $ 6,856.40 | *$ 49,247.95* |
| Langstaff Connection | Option 8 | $ 5,191.66 | $ 8,327.05 | $ 7,468.70 | *$ 57,770.56* |

**Table 3 – Cost-Benefit Ratios by Strategy**

| Strategy | | Cost of Congestion Benefits | Expected Life (yrs) | Costs | Benefit/Cost |
|---|---|---|---|---|---|
| | | | | | |
| *Keele St. Widening* | Option 1 | $ 5,008.27 | 15 | $ 3,650,000 | 5.15 |
| *CN/Hwy 7 Access* | Option 2 | $ 165.52 | 15 | $ 1,000,000 | 0.62 |
| *Grade Separation* | Option 3 | $ 7,341.64 | 15 | $ 8,500,000 | 3.24 |
| *WB/EB LT Flyovers* | Option 4 | $ 6,012.04 | 15 | $ 8,200,000 | 2.75 |
| *Point Diamond Interchange* | Option 5 | $ 8,131.91 | 15 | $ 11,000,000 | 2.77 |
| *Network Optimization* | Option 6 | $ 4,717.76 | 1 | $ 50,000 | 23.59 |
| *Traffic Adaptive Control* | Option 6b | $ 4,717.76 | 5 | $ 500,000 | 11.79 |
| *ITS (2%) all* | Option 7 | $ 2,120.58 | 10 | $ 250,000 | 21.21 |
| *ITS (5%) all* | Option 7 | $ 5,618.28 | 10 | $ 250,000 | 56.18 |
| *ITS (10%) all* | Option 7 | $ 10,058.38 | 10 | $ 250,000 | 100.58 |
| *Langstaff Connection* | Option 8 | $ 1,535.77 | 15 | $ 40,000,000 | 0.14 |

**Figure 1: Study Area**

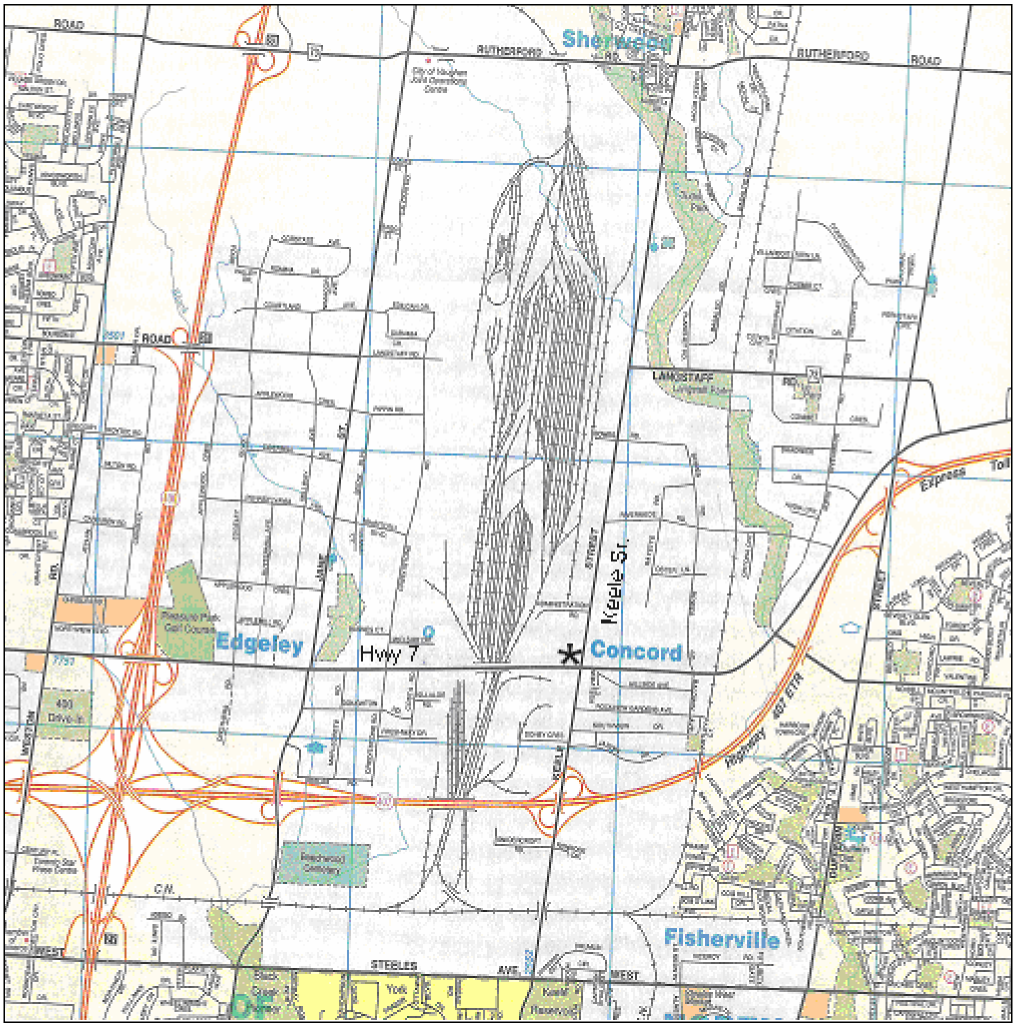
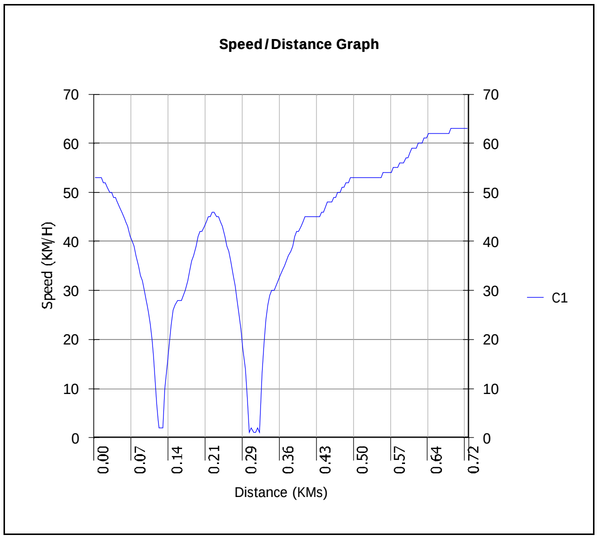


**Figure 2: Westbound Speed Profiles through Highway 7 at Keele Street**



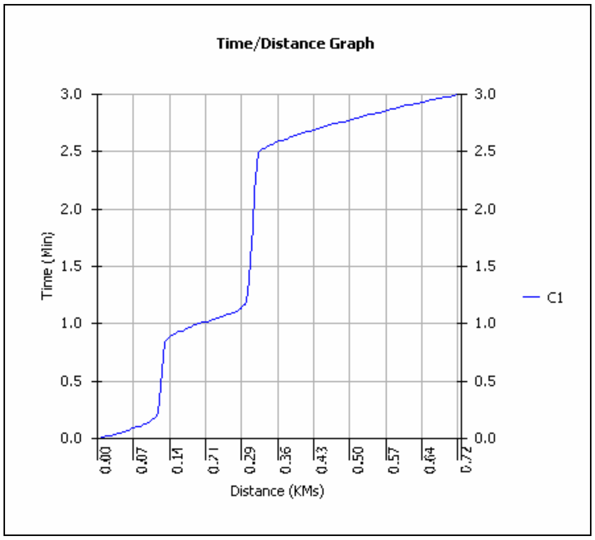




Figure 2 illustrates the iTREC output for the westbound travel through the intersection of Highway 7 at Keele Street and shows that delay through two cycles was experienced before proceeding through the intersection. It also shows that it took 3 minutes to travel approximately 700 metres from the back of queue through the intersection.